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Harvester perceptions of climate vulnerability: Contributions to building climate resilient fisheries

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The uncertainty of future ocean conditions caused by climate change challenges the conventional fisheries management model that assumes resource extraction occurs in a steady-state environment. As managers respond to climate impacts and focus on long-term preparedness, an overarching goal is to minimize the vulnerability of fishing businesses and communities. However, during the adaptation process, challenges can arise when perceptions of climate change vulnerability differ among scientists, managers, and harvesters. A harvester's perception of their risk to climate change influences their willingness to plan for and respond to change, yet these views are often overlooked in adaptation planning. To better understand this dynamic, we conducted a regional survey to evaluate the perceptions harvesters hold regarding the impacts of climate change on commercially fished species in the Northeastern United States and the resulting risks from those changes. The waters in this region of the Northwest Atlantic shelf are warming faster than the global average resulting in shifting distributions of species, altered seasonal migrations, and changes in productivity. Respondents' perceptions aligned with an analysis conducted by scientists on the directionality of climate impacts for 12 out of 27 (44%) of the most commercially important species in the region. Additionally, an understanding of the variability in perceptions of climate change vulnerability emerged: 72% of respondents believe climate change is occurring, 53% believe climate change will harm them personally, and 28% have already seen a negative impact on their ability to catch fish. Respondents who believe that climate change is occurring had higher perceptions of vulnerability on average than those who do not believe it is occurring. Despite a sense of vulnerability to climate change, respondents did not rank it among the top three concerns (fisheries regulations, market access, and access to working waterfronts) for their fishing businesses. Investigating harvester's perceptions is an opportunity to share their experiences and understand the diversity of perspectives regarding the impacts of climate change. Increasing the inclusion of social science indicators and diverse perspectives will increase climate resilience of fisheries management.

KEYWORDS

vulnerability assessment, climate change concerns, plurality of perspectives, social-ecological systems, New England (USA)

Introduction

Climate change has an amplifying effect on current and persistent issues confronting fisheries. Significant changes in ocean temperatures have resulted in shifts in species distribution in ecosystems across the globe, in seasonal timing, and productivity, including on the East Coast of the United States (Merzouk and Johnson, 2011; Pinsky and Fogarty, 2012; Hale et al., 2017; Kleisner et al., 2017; Amstutz et al., 2021). In the Northwest Atlantic Shelf, upper ocean waters are warming two to three times faster than the global average (Saba et al., 2016) and autumnal bottom temperatures have increased 0.8°C in this region over the past 45 years (Kleisner et al., 2017). Mobile fish and invertebrates targeted by commercial fisheries are either shifting poleward or into deeper waters because of changing ocean conditions (Pinsky and Fogarty, 2012; Hare et al., 2016; Kleisner et al., 2017). Species distribution shifts outside of historically managed boundaries can cause loss of fisheries access or increases in the cost of fishing by requiring harvesters to travel further in pursuit of target species, or investing in gear, permits, or quota to harvest new species (Pinsky and Fogarty, 2012; Pinsky and Mantua, 2014; Dubik et al., 2019). Shifting distributions of species have important implications; fisheries may be limited in their traditional regions while new fishing opportunities may be created in other areas (Pinsky and Mantua, 2014). Altered distributions and new species may also result in a lack of appropriate shoreside infrastructure and markets (Coulthard, 2009; McCay, 2012).

Some of these effects are already being felt by harvesters and a shift to climate-resilient fisheries management is urgently needed (Holsman et al., 2019; Lomonico et al., 2021). To be successful, climate-resilient fisheries management must reflect a diversity of perspectives on the social and ecological impacts of climate change (Holsman et al., 2019; Levin et al., 2021). A diversity of perspectives can result in the phenomenon of "plurality of reality" where multiple believable, but at times contradictory, interpretations of reality exist at the same time (Levin et al., 2021). Acknowledging and merging the existence of the "plurality of reality" can vastly improve problem solving (Page, 2007; Levin et al., 2021). Ideally, this shift in management would also combine diverse perspectives regarding long-term preparedness needs of individuals (Marshall, 2014), and an understanding of how harvesters perceive their own vulnerability to climate change and how that varies within a fishery or region.

The explicit assessment of variation in the risks across fisheries, regions, or individuals helps move towards more climate resilient fisheries and fishing communities by allowing managers to better understand these complex social-ecological systems and to develop realistic and equitable solutions (Hodgson et al., 2019). Climate vulnerability assessments are used to evaluate the risk of individuals, communities, or systems to the impacts of climate change and their capacity to respond to those risks (e.g., Cinner et al., 2012; Marshall et al., 2013; Himes-Cornell and Kasperski, 2015; Koehn et al., 2022). There are a multitude of frameworks utilized to measure vulnerability. Some (Mathis et al., 2015; Payne et al., 2021) choose to use the newer, risk-centric framework developed by the IPCC (2012), while others develop their own conceptual frameworks, grounded in similar concepts but tailored to a particular system (Dudley et al., 2021). The framework employed in this work is the widely used exposure, sensitivity, and adaptive capacity framework conceptualized during early work for the IPCC (IPCC, 2001; Brooks, 2003; Adger, 2006). Exposure is assessed by how and to what extent a system experiences stressors such as climate change, and sensitivity evaluates the degree to which systems or individuals will be affected by those changes (Adger, 2006). Exposure and sensitivity combined equate to the potential impact on the system, which here is defined as risk (e.g., Samhouri and Levin, 2012), and adaptive capacity is the set of circumstances or choices an individual can make to respond and to moderate or cope with that risk (Grothmann and Patt, 2005). Vulnerability is a function of risk moderated by adaptive capacity (Adger, 2006; Marshall et al., 2013)

Frequently, climate vulnerability assessments of fisheries fail to include perceptions of commercial harvesters (Hodgson et al., 2019). This approach not only overlooks knowledge held by harvesters, but also ignores how an individual may be evaluating their own exposure to risks attributable to climate change. Understanding harvester perceptions is important because we know there are gaps between climate scientists' and public perceptions of the risks from climate change (Ballew et al., 2019; Howe et al., 2019), and if individuals do not perceive something as a risk, they will not be motivated to adapt (Grothmann and Patt, 2005). Additionally, environmental management considerations and actions are a direct result of assessing risk (Burgman, 2005; Gaichas et al., 2018; Samhouri et al., 2019). Therefore, it is important for resource managers to understand where there is a mismatch in risk perception between themselves and resource users, or a plurality of reality of the current situation (Levin et al., 2021). Previous research focusing on fishers and farmers in rural contexts highlighted differences between individual perceptions and external metrics of climate-related risk to farming and fishing livelihoods, with implications for decisions about taking action to adapt to or manage those risks (Cullen and Anderson, 2017; Cullen et al., 2018). Understanding the views of harvesters regarding climate impacts on their target species and their own risk levels can be a starting point for discussing the long-term preparedness needed for fisheries to adapt to climate change.

This study investigates three questions centered on perceptions of climate vulnerability: 1) What do commercial harvesters in New England think about climate change? 2) What impacts do they think climate change is having on commercial fisheries? and 3) How do they view themselves as being vulnerable to those changes? Harvester perceptions of vulnerability are evaluated based on their perception of their exposure to climate change, how sensitive they are as individuals to changing conditions, and perceptions of their ability to adapt to change. Vulnerability is calculated for each respondent to assess the average vulnerability by participation in different fisheries and regions within the Northeast United States. To identify potential gaps in the perceived risk of climate change between harvesters and the scientific community on fisheries, we compared perceptions of the impacts of climate change on a species from survey participants to the prevailing scientific understanding based on Hare et al. (2016). The resulting information can be used in a management and planning context where harvester's lived experiences are considered and the plurality of perspectives of the impacts of climate change are acknowledged in order to work toward climate resilience (Holsman et al., 2019).

Methods

Survey

New England harvesters from Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut (Figure 1) were surveyed between July 1 and August 31, 2020, to understand their perceptions of the impacts of climate change and other stressors on commercial fisheries. The survey instrument was initially developed for the West Coast (Nelson, 2023) and the species, gear types, and regions were adapted for New England. The survey consisted of 49 questions, contained within three components: 1) demographics and fishery participation information, 2) harvester observations of a changing ocean, and 3) perceptions of wellbeing and vulnerability. The survey instrument utilized established indicators of wellbeing and social vulnerability (Colburn et al., 2016; Breslow et al., 2017) and methods for assessing climate risk perception (Cullen and Anderson, 2017). Likert-scale questions were used to gauge harvester perceptions of changes in the distribution of several commercially harvested species, changing ocean conditions, wellbeing, and adaptive capacity. Open-ended questions were used to gather additional detail about changing environmental conditions and challenges to adaptation. The full survey instrument can be found in Appendix A of the supplemental material and the survey, data analysis, and data from this and parallel studies in other regions can be found on GitHub (https://github.com/lknelson05/climate_perceptions at the NE branch).

This was an online survey with a corresponding sweepstakes with entry information at the beginning and end of the survey. Harvesters in Maine, Massachusetts, and Connecticut were emailed directly while harvesters in New Hampshire and Rhode Island received a link to the survey from their respective state fishery management agency as regulations in these states prevent the sharing of license holder information. In Maine, there were 7,053 individuals with a 2019 commercial fishing license, of which email addresses were available for 5,395 harvesters. In Massachusetts, there were 7,031 registered permit holders in 2019 of which email addresses were available for 5,320. In Connecticut, there were 332 individual registered license holders in 2020 of which email addresses were available for 275. Emails with an invitation and link to the online survey were sent to all individuals who provided an email address to the state in New Hampshire and Rhode Island. New Hampshire sent the survey link to 447 license holders in 2020 and the number of recipients in Rhode Island was not reported back.

Climate change vulnerability indices

In this study we consider vulnerability to be a function of the exposure and sensitivity of an individual, which collectively we call risk, and their adaptive capacity. A series of survey questions were used to construct the exposure, sensitivity, and adaptive capacity indices. Vulnerability was calculated at the individual level to be able to evaluate how demographics and beliefs impact an individual's perceived vulnerability. Exposure is calculated as the mean of an individual's responses to their perception of the impact of ocean warming on the species they target (Supplemental Material Appendix B, Figure B1). Sensitivity is calculated as the mean of responses to a series of questions gauging how changes in the environment and fisheries has affected their health and wellbeing (Appendix B, Figure B2). The adaptive capacity of an individual is calculated as the

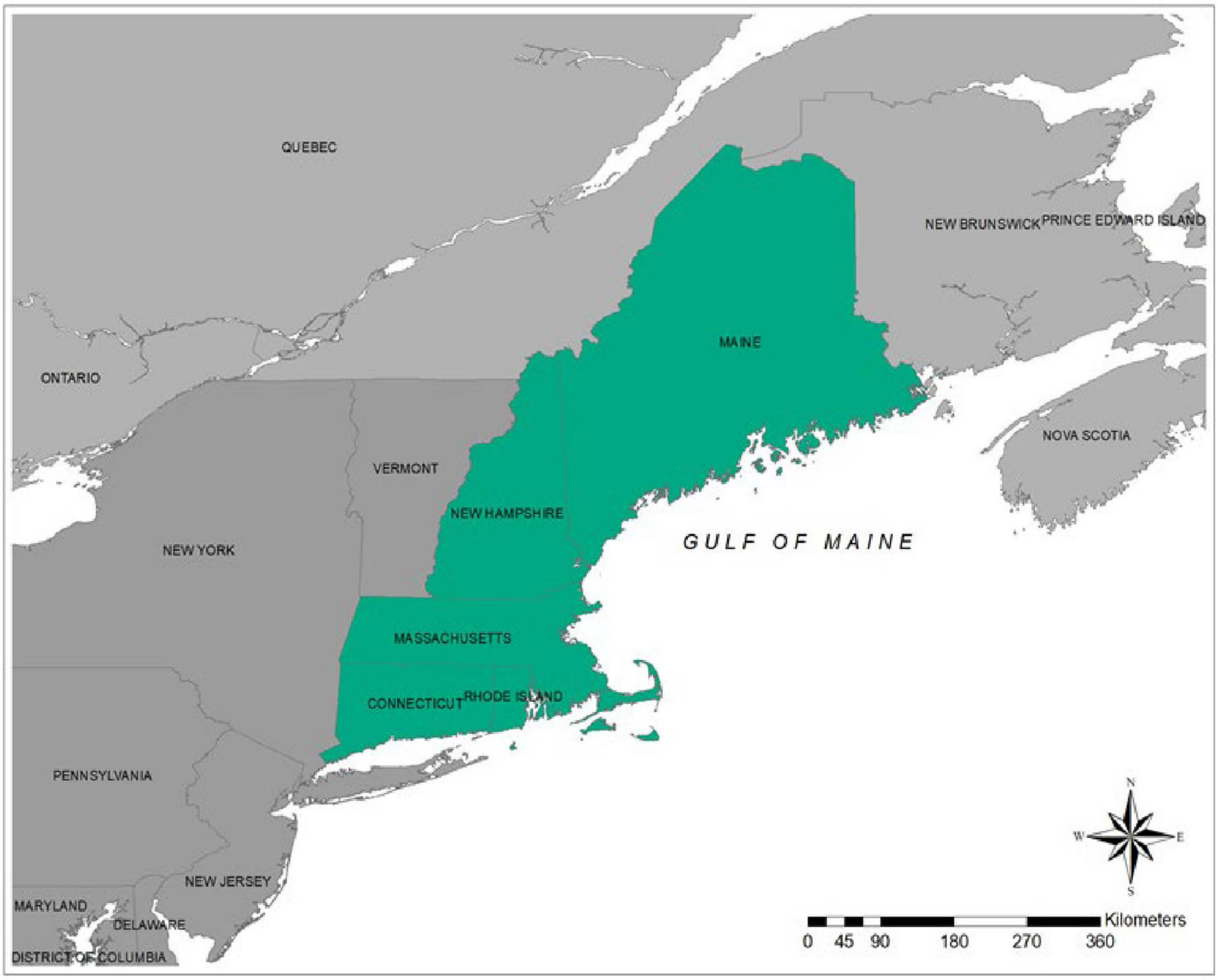

FIGURE 1
New England states included in the survey, and highlighted in green, are Maine, New Hampshire, Massachusetts, Connecticut, and Rhode Island.

average of a series of questions asking about the future security of themselves, their community, and their fishery (Appendix B, Figure B3; Nelson, 2023). Categorical responses (i.e., somewhat, very, none) for the Likert-scale questions were changed to numerical responses (0-1) to first calculate an individual's risk (r) as the Euclidean distance from the origin with axes defined by exposure (e) and sensitivity (s) (Samhouri and Levin, 2012; Eq. 1). Vulnerability (v) is also calculated using the Euclidean distance method (Samhouri and Levin, 2012) with risk and adaptive capacity (ac) as the axes for space and vulnerability expressed by distance from the origin (Eq. 2). The higher the vulnerability score, the more vulnerable that individual perceives themself to be. Variables e, s, and ac are equally weighted as there is no information to apply a different weighting scheme.

$$r = \sqrt{(\bar{e}^2 + \bar{s}^2)} \quad \text{Eq.1}$$

$$v = \sqrt{r + (1 - \overline{ac})^2} \quad \text{Eq.2}$$

Previous work has shown variability in the climate risk among harvesters participating in different fisheries in New England (Rogers et al., 2019). To understand if harvesters participating in certain fisheries perceive themselves as more vulnerable to climate change, the average vulnerability scores across fisheries were calculated and compared relative to each other along isoclines that capture the range of risk and adaptive capacity along the axes and vulnerability that increases as it radiates from the origin. Using all the data combined, we also explored whether there were differences in perceived vulnerability depending upon how fishers responded to the question "I believe that climate change is occurring" using a Kruskal-Wallis analysis of variance (ANOVA) and pairwise t-tests with a Bonferroni correction using R statistical software (v 4.0.3; R Core Team, 2020).

Fisheries and climate change

Survey respondents were asked to indicate what, if any, effect they believe ocean warming is having on specific fisheries (strong or slight negative effect, no effect, or a slight or strong positive effect). These observations are used in the vulnerability indices described above and are additionally valuable as these perceptions can be compared to scientific evaluations of the impacts of climate change on these species. Hare et al. (2016) conducted a "Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf", that evaluated the impacts of climate change on the same species included in this study, utilizing quantitative assessments when available and qualitative data or expert elicitation to fill in gaps. The perceptions of survey respondents of the impacts of climate change on their target species from this survey were compared qualitatively to the results in Hare et al. (2016). The impact of climate change on a species or species group was determined based on how the majority of respondents targeting a species responded, the response options listed above were grouped into positive, negative, or neutral for this evaluation. In Hare et al. (2016), scientists evaluated the sensitivity and exposure of each species to a range of different attributes resulting in vulnerability scores on a four-point scale (low, moderate, high, very high). Based on the vulnerability scores, the directional effect of climate change on each species was categorized into three groups: positive, negative, or neutral. The directional effect of climate change from Hare et al. (2016) (positive, negative, or neutral), was compared to the survey responses from this study.

Results

The vast majority (72%) of the 418 New England survey respondents believe climate change is occurring. The majority (60%) of survey respondents have been fishing for more than 25 years and are between the ages of 50 and 70 years old (Table 1), giving them multiple decades of experience to inform their perspectives. The number of responses by State varied greatly: 49.8% were from Maine (ME), 2.9% were from New Hampshire (NH), 40% were from Massachusetts (MA), 2.9% were from Rhode Island (RI), 3.1% were from Connecticut (CT), and 1.4% were from New York and New Jersey (NY/NJ) combined (Table 1).

About two-thirds of respondents have observed an increase in ocean temperatures and just under half report a decrease in target species catches (Figures 2A, B). Despite reporting direct observations of the impacts of ocean warming, only 28% of survey respondents report climate change as having had a negative impact on their ability to catch fish (Figure 2C). Given these responses, it is interesting that 53% of respondents expect climate change to harm them personally, while 68% expect climate change to harm future generations.

Over half of survey respondents (55%) think that climate change should be included in fisheries management and 52% do not think that fisheries management could adapt and respond quickly to changing environmental conditions. Only 29% reported feeling like the fisheries they participate in are managed in an equitable way. Survey respondents also reported feeling constrained in their ability to adapt to climate change because of fisheries regulations (56%). Changes in fisheries are negatively impacting the overall health and wellbeing of survey respondents: 72% report it has increased their stress levels, 67% report negative impacts to overall wellbeing, and 51% report negative impacts to their mental health (Appendix B, Figure B2). When survey respondents were asked what their top three concerns are regarding their fishing businesses (at the time of the survey), only 23% reported climate change among their top three concerns. Given that "changes in fisheries" could encompass all aspects of fisheries, it is helpful to understand that respondents had fisheries regulations (69%), market access due to COVID-19 (50%), and affordable access to working waterfronts (35%) as their predominant concerns (Figure 3).

Climate change vulnerability indices

There were statistical differences in perceived vulnerability (p-value<0.001; Table 2) depending upon how individuals responded to the statement, "I believe climate change is occurring" (Figure 4).

TABLE 1 Demographic summary and the perception of climate change of survey respondents.

State	%	Age Group	%	Vessel Size (ft)	%	Income from outside fishing (%)	%	Climate Change Will Harm Me	%
ME	49.8%	U30	4.8%	U25	45%	None	23%	Agree	53%
NH	2.9%	30-40	10.5%	26-35	24%	U10	16%	Neutral	25%
MA	40%	40-50	19.6%	36-45	26%	10-25	9%	Disagree	22%
RI	2.9%	50-60	25.1%	46-55	2%	25-50	8%		
CT	3.1%	60-70	28%	56-65	1%	50+	44%		
NY/NJ	1.4%	70+	12%	66+	2%				

State abbreviations are Maine - ME, New Hampshire - NH, Massachusetts - MA, Rhode Island - RI, Connecticut - CT, New York - NY, and New Jersey - NJ.

Survey respondents who believe that climate change is occurring had higher vulnerability scores on average than those who are neutral (p-value adjusted< 0.001) or disagreed (p-value adjusted< 0.001) with that statement (Table 2). There was no statistical difference in average vulnerability between those that were neutral and those that do not believe in climate change (p-value adjusted = 0.42; Table 2). There were also statistical differences for each component of vulnerability based on belief in climate change (Table 2). Individuals who believed climate change is occurring had higher perceived exposure and lower adaptive capacity compared to those who were neutral or disagreed (Table 2). Individuals who agreed with climate change had higher sensitivity than those who disagreed, but there was not difference between those who agreed or were neutral on the statement (Table 2).

Survey respondents with the highest average perceived vulnerability to climate change were those targeting demersal fish species, specifically species in the New England Fisheries Management Council's (NEFMC) small-mesh multispecies complex, NEFMC multispecies groundfish complex, and the benthic species jointly managed with the Mid-Atlantic Fisheries Management Council (MAFMC), the Atlantic States Marine Fisheries Commission (ASMFC), and NEFMC (Appendix C, Supplementary Material).

There was variability in average perceived vulnerability and the components (i.e., exposure, sensitivity, and adaptive

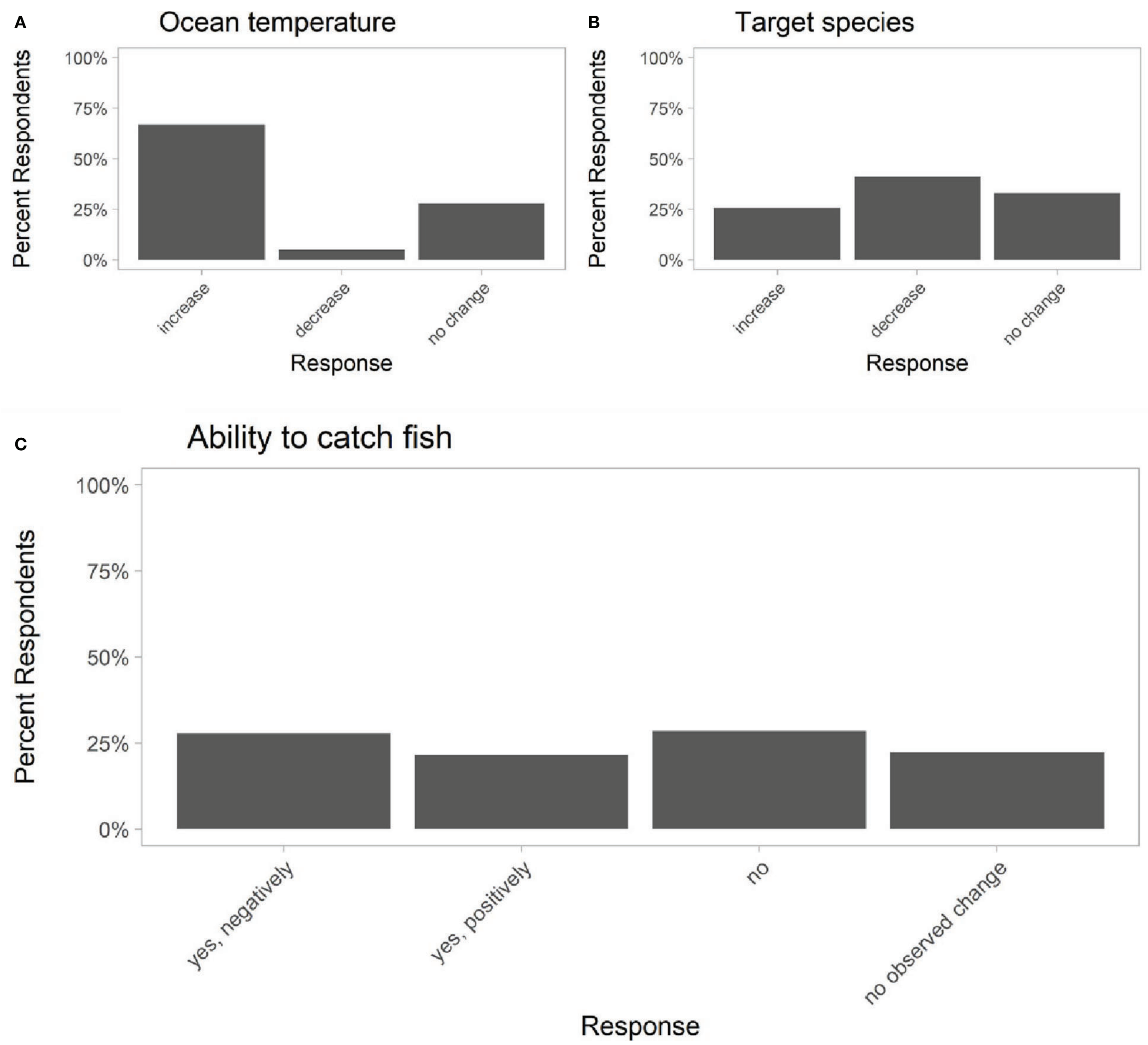

FIGURE 2
Survey respondents' observations of climate change over the past five years regarding **(A)** ocean temperature, **(B)** target species abundance, and **(C)** perceptions of the impact of climate change on their ability to catch fish.

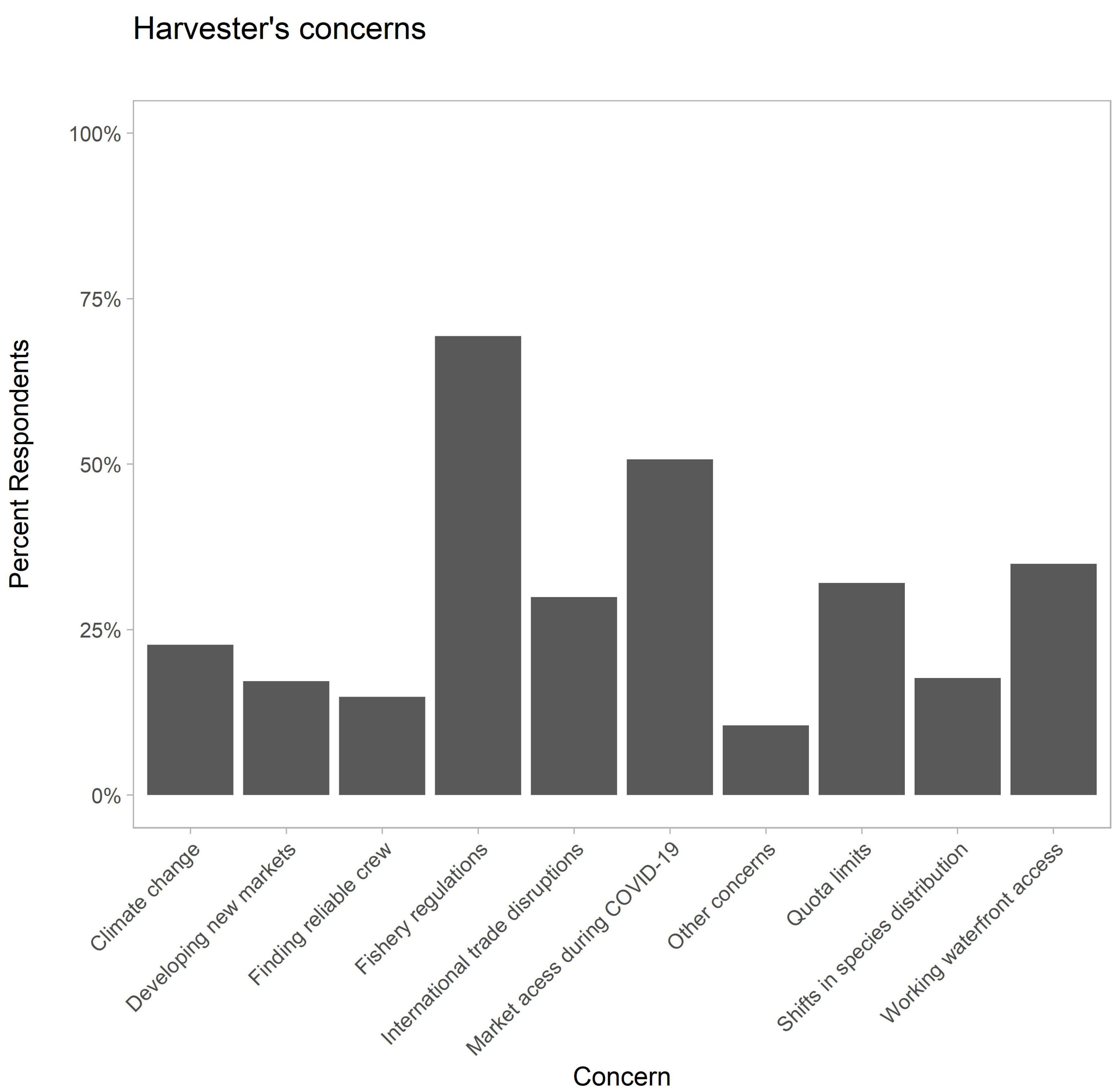

FIGURE 3
Harvester perceptions regarding the main concerns affecting their fishing business. Respondents were given the opportunity to indicate their top concerns regarding fishing businesses and were able to select 3 of the 10 options above.

capacity) across fisheries and management bodies. Red hake and whiting/silver hake were among the fisheries with the highest relative perceived vulnerability, though the components driving the higher scores were different. Harvesters participating in the NEFMC small-mesh fishery for whiting/silver hake (*Merluccius bilinearis*) had the highest average perceived sensitivity (e.g., stress or impacts to wellbeing) while participants targeting red hake (*Urophycis chuss*) had the highest average perceived exposure (e.g., climate change impacting species distribution; Appendix C, Supplementary Material). The 20 survey respondents participating in the NEFMC small-mesh fishery also perceived their adaptive capacity to be low (e.g., limited access to capital), contributing to the high perceived vulnerability (Figure 5). At the other end of the spectrum, the 71 survey respondents participating in the menhaden (*Brevoortia tyrannus*) and 36 respondents participating in the Atlantic halibut (*Hippoglossus hippoglossus*) fisheries perceived their vulnerability to be relatively low, seeing themselves as having low risk and relatively high adaptive capacity (Figure 5). Of the survey participants targeting menhaden, all

TABLE 2 Mean (and standard deviation) of the vulnerability scores aggregated by belief if climate change is occurring, and results of the Kruskal-Wallis analysis of variance (ANOVA) and pairwise t-tests.

		Exposure	Sensitivity	Adaptive Capacity	Vulnerability	count
Agree		0.61 (0.26)	0.47 (0.23)	0.41 (0.15)	1.01 (.25)	300
Disagree		0.49 (0.21)	0.38 (0.21)	0.46 (0.14)	0.87 (0.18)	64
Neutral		0.52 (0.18)	0.43 (0.20)	0.46 (0.13)	0.90 (0.19)	54
Kruskal-Wallis	Chi-squared	16.69	10.91	11.23	27.03	
	p-value	<0.001	0.004	0.004	<0.001	
Pairwise t-tests						
Agree - Disagree		0.008	0.005	0.023	< 0.001	
Agree – Neutral		0.007	0.18	0.023	< 0.001	
Disagree - Neutral		0.51	0.18	0.84	0.42	

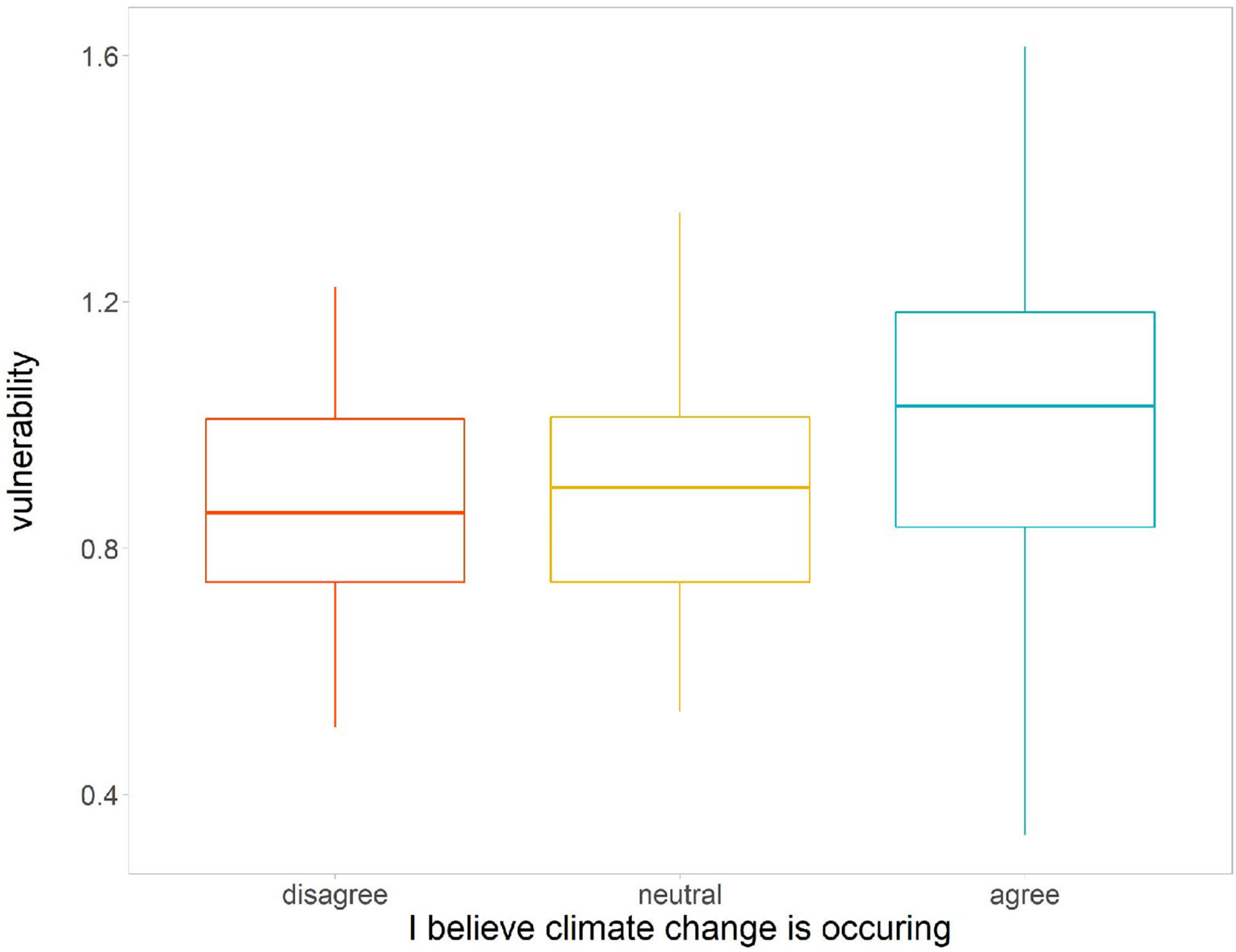

FIGURE 4
Distribution of perceived vulnerability scores based on whether respondents agreed (blue), were neutral (yellow) or disagreed (red) with the question "I believe climate change is occurring".

but one also targets other fisheries, and all respondents targeting Atlantic halibut also target other fisheries.

The relatively high perceived vulnerability in other fisheries was driven by a variable mix of levels of risk and adaptive capacity (Appendix C, Supplementary Material). Survey respondents participating in the skates, redfish, and American plaice fishery had some of the highest perceived risk and lowest perceived adaptive capacity, placing them among the fisheries with the higher relative vulnerability (Figure 5). Harvesters participating in the witch flounder and red crab fisheries had moderate risk but low adaptive capacity, resulting in higher relative vulnerability as well (Figure 5). While participants in the monkfish (*Lophius americanus*), scallop (*Placopecten magellanicus*), white hake (*Urophycis tenuis*), Atlantic cod (*Gadus morhua*), and pollock (*Pollachius virens*) fisheries exhibit higher levels of perceived adaptive capacity, they still have higher overall vulnerability because of their high risk (Figure 5). Survey respondents participating in the yellowtail flounder (*Limanda ferruginea*), combined clam species, haddock (*Melanogrammus* aeglefinus) and striped bass (*Morone saxatilis*) fisheries had moderate relative vulnerability, all located in the green isocline in Figure 5.

Fisheries and climate change

Harvester perceptions of the impact of climate change on commercially important species in the Northeast were compared

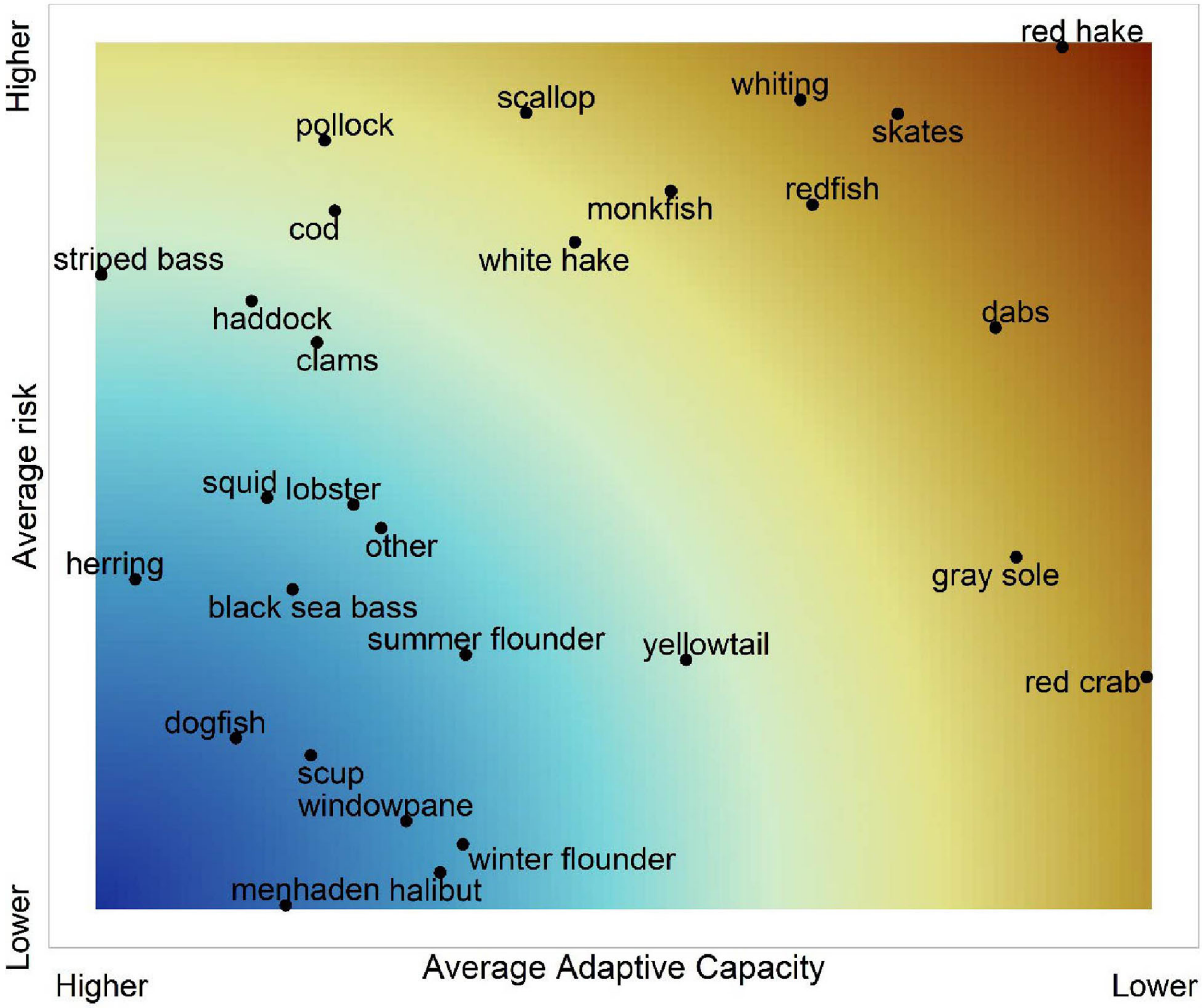

FIGURE 5
Average relative vulnerability of survey respondents participating in Northeast commercial fisheries indicated by the distance from the origin in a space defined by risk (exposure and sensitivity) and adaptive capacity. The colored bands represent similar levels of perceived vulnerability. Since higher adaptive capacity reduces vulnerability, the adaptive capacity axis goes from highest to lowest calculated values.

to the empirical vulnerability assessment conducted by Hare et al. (2016). Respondents' perceptions aligned with the empirical based analysis on 41% of the 27 species included in this study, there was divergence for 52% of the species, and 7% could not be compared because of different species groupings (Table 3). Amongst the areas of divergence, harvesters think that climate change is having a neutral impact on 8 species while Hare et al. (2016) reported a negative impact on the same 8 including haddock, halibut, white hake, dabs/American plaice (*Hippoglossoides platessoides*), gray sole/witch flounder (*Glyptocephalus cynoglossus*), Acadian redfish (*Sebastes fasciatus*), whiting/silver hake (*Merluccius bilinearis*), and clams (Table 3). For American lobster (*Homarus americanus*), summer flounder (*Paralichthys dentatus*), red hake, and striped bass, the Hare et al. (2016) analysis indicates that climate change is projected to have a neutral impact while harvesters targeting those species think that climate change is having a negative impact on them (Table 3). Respondents also think that climate change is having a neutral impact on squid, while Hare et al. (2016) report a positive impact. The discrepancy in the

TABLE 3 Comparison of the perceptions of the impact of climate change on various fishery species in the Northeast between harvesters (this study) and scientists (reported in Hare et al., 2016).

Species	Harvesters (Targeting the species)	Scientists (Hare et al 2016)
American Lobster	Negative	Neutral
Atlantic herring	Negative	Negative
Atlantic Menhaden	Positive	Positive
Scallop	Negative	Negative
Atlantic cod	Negative	Negative
Haddock	Neutral	Negative
Pollock	Negative	Negative
Halibut	Neutral	Negative
White hake	Neutral	Negative
Dabs/American plaice	Neutral	Negative
Gray sole/witch flounder	Neutral	Negative
Windowpane flounder	Neutral	Neutral
Yellowtail	Negative	Negative
Winter flounder	Negative	Negative
Acadian redfish	Neutral	Negative
Monkfish	Neutral	Neutral
Skates spp.	Neutral	Variable by species
Whiting/silver hake	Neutral	Negative
Red hake	Negative	Neutral
Red crab	No Consensus	Neutral
Clams	Neutral	Negative
Squid spp.	Neutral	Positive
Dogfish	Neutral	Neutral
Summer flounder	Negative	Neutral
Scup	Positive	Positive
Black sea bass	Positive	Positive
Striped bass	Negative	Neutral

Red means negative impact of climate change, yellow means neutral or no impact, and blue means a positive impact. Species highlighted in grey indicate where there is disagreement between the two groups, with dark gray indicating harvesters perceiving a worse impact and light gray indicating scientists perceiving a worse impact.

perceptions of the impact of climate change on specific species may be contributing to 48% of survey respondents thinking that the fisheries they participate in are managed ineffectively.

Discussion

Sustainable fisheries management needs to consider climate-driven impacts on the vulnerability of harvesters (Gaichas et al., 2018; Koehn et al., 2022; Nelson et al., 2022). The majority of survey respondents in this study expressed a desire to have climate change incorporated into fisheries management. However, this study highlights the complex nature of perceptions of the impacts of climate change and the variability that exists across and within fisheries. Most survey respondents expect climate change to harm them and future generations, and report observing increases in ocean temperatures. At the same time, most harvesters did not report a decrease in catches of target species and did not report that climate change is having a negative impact on their ability to harvest fish. The harvester's responses also highlighted the variable impacts of climate change, with respondents reporting that they believe climate change is benefiting some species while negatively impacting others. Even so, most respondents reported that they are experiencing increased stress and negative impacts on their overall wellbeing and mental health from changes in fisheries and the environment. Based on responses to what harvesters are most concerned about regarding their fishing businesses, these changes likely include regulations and access to markets, working waterfronts, and quota. These are all aspects of a fishing business that can be negatively impacted by climate change. Considering the complexity of these beliefs and the reported impacts on overall wellbeing from changes in the environment, it is not surprising that participants that do express a recognition of the threat of climate change had a higher perceived vulnerability than those who do not express such recognition.

The physical and ecological changes that cascade through social-ecological systems because of climate change results in impacts to fishing communities and present numerous management challenges (Barange et al., 2018). Most survey respondents were not confident in their ability to travel further to fish if needed, nor were they confident in the viability of their community into the future. Additionally, most survey respondents expressed the perception that fisheries management could not adapt quickly to changing environmental conditions and that climate change should be considered in fisheries management. Management practices that are climate-resilient have been linked to more productive and profitable fisheries globally (Free et al., 2020). However, across U.S. fisheries, climate information has thus far played a limited role in management decisions (GAO, 2022).

Given the diverse perspectives collected in this survey, there are competing views for fisheries managers to consider when identifying the best path forward for incorporating climate change into the management process and communicating the benefits. For instance, harvesters in this study targeting Atlantic halibut had a lower average perceived vulnerability score than individuals targeting American plaice (dabs). These two species are managed under the same multispecies fisheries management plan at the New England Fisheries Management Council (NEFMC, 1985). Atlantic halibut are typically targeted in state waters (within 3 miles of shore) with longline gear (Hansell et al., 2020). American plaice are targeted offshore with trawl gear, a gear type that also catches Atlantic halibut in federal waters (more than 3 miles from shore to the 200-mile Exclusive Economic Zone). Context and differences in fishing grounds and gear type can contribute to different perceptions of management effects on wellbeing (Chan et al., 2019) and here likely contributes to varying perceptions both of overall climate vulnerability, as well as the individual components. This may lead these harvesters to form different conclusions about what climate strategies should be prioritized in this fisheries management plan, leaving managers to reconcile a "plurality of realities" (*cf.* Levin et al., 2021).

Elucidating harvester perceptions of climate vulnerability can provide insight into how fisheries regulations aimed at addressing climate impacts may or may not align with, or address, what harvesters consider to be the biggest risks to themselves or their communities (Nelson et al., 2022). Risk perceptions are influenced by recent events and current conditions more heavily than future possibilities (Clayton et al., 2015), necessitating that managers communicate how addressing climate change will also benefit other issues. In the Atlantic halibut and American plaice example, Atlantic halibut are considered overfished while American plaice is not overfished or experiencing overfishing (NEFMC, 2022). For example, the investment in longline gear for Atlantic halibut is much less than the investment in trawl gear and a vessel big enough to maneuver a trawl net. Additionally American plaice are managed through a quota system while Atlantic halibut are not. Because access to quota was a concern for respondents, this difference may have affected the perceptions of vulnerability of harvesters. Capturing and considering these nuances that impact harvesters, their financial risks, and ultimately their perceived vulnerability requires stakeholder engagement processes and planning initiatives aimed at increasing the resilience of harvesters and fisheries-dependent communities. These initiatives will need to incorporate: 1) how harvesters view their own risk to changing climatic conditions, 2) the impacts climate change is having on their target species, and 3) harvesters' immediate priority concerns. It will also require understanding what is needed for individuals to adapt, as well as an understanding of the emotional and physical toll these changes are having on the community.

Perceptions of risk

Decision makers are faced with increasing uncertainty from changing ocean conditions. (Barange et al., 2018). The ability to make decisions in the face of general uncertainty or in the face of quantifiable scientific uncertainty requires managing overall risk to the social-ecological system (Gaichas et al., 2018). Dedicating the resources necessary to evaluate risks from climate change on natural resource-based communities should be an important consideration in the policy and management decisions being made in response to the realized impacts of climate change (Colburn et al., 2016; Cullen and Anderson, 2017; Cullen et al., 2018; Holsman et al., 2019). Responses to changing conditions are driven by perceptions of the best way to minimize vulnerability and support wellbeing (Eiser et al., 2012). However, the complexity of a social-ecological system can make it difficult to determine what actions to prioritize to reduce vulnerability (Nelson et al., 2022). A social-ecological systems framework may help bring order to an overwhelming number of issues and information to increase system resilience (Ostrom, 2009; Leslie et al., 2015) and a critical early step is assessing the range of risks in a system that need to be addressed in the management context (Gaichas et al., 2018; Levin et al., 2018, Nelson et al., 2022).

Policies that promote better participation, including various forms of cooperative management, can increase harvesters' resilience and adaptive capacity to climate change (Wilson et al., 2018; Free et al., 2020). Based on responses to open-ended questions, harvesters signaled a desire for increased participation, and for co-management approaches where they are listened to more and play a more central role in the management process. For example, one respondent stated: "*Listen better to the men and women in specific fisheries, they are the ones on the front lines and if [their] fishery is in trouble they will be out of a job, so they won't let that happen.*" With increased participation, management agencies can also develop a shared understanding of climate risk through long-term planning activities where managers and harvesters can each share how they view vulnerability to climate change.

Engaging stakeholders in long-term planning is a way to fully include harvesters in the process of preparing for climate change. Scenario planning, one approach to long-term planning, is a structured means to examine if the current decision-making processes will be suitable in an uncertain future (Raskin et al., 2005; Duinker and Greig, 2007; Alcamo, 2008; Bell et al., 2020). It does not try and predict the future, but simply examines the range of potential futures to determine effective ways to make decisions despite uncertainty. By working through the scenarios, participants are forced to identify and critically examine their own assumptions about the future and analyze the main factors driving potential outcomes, their connections, and feedback loops (Rowland et al., 2014). Each scenario represents a narrative about the future that is plausible and is not intended to be treated as a forecast. By working through the range of scenarios, harvesters, scientists, and managers can collaboratively develop effective strategies and actions to reduce risk and prepare for climate change across a range of possible scenarios (Rowland et al., 2014).

Impacts to species

This study identified that the perceptions of the impacts of climate change on species may differ among harvesters and scientists, a finding not unique to this study (e.g., McClenachan et al., 2022). These differences in perception will cascade into the management process and likely impact managers' views. Here, harvesters indicated they see climate change as having a neutral impact on several species that Hare et al. (2016) found to be experiencing negative impacts. There were four species (American lobster, red hake, summer flounder, and striped bass) for which Hare et al. (2016) found a neutral impact from climate change while harvesters in this study perceived a negative impact. This discrepancy could be a function of how each of the studies was conducted or a reflection of differences in how scientists and harvesters are evaluating the risk of climate change. A closer look at the American lobster and striped bass fisheries reveals differences in the circumstances around these two species and fisheries that may be driving differences in perceptions of the impacts of climate change.

We consider the American lobster first. This species ranges from Newfoundland, Canada to the Mid-Atlantic region of the United States. Every life history stage of American lobster is strongly influenced by water temperature (ASMFC, 2021). The Gulf of Maine/Georges Bank stock has seen increased recruitment because of the population spending extended periods of time in the optimal temperature range (12° - 18°C; ASMFC, 2021), due to warming waters in the Gulf of Maine (Saba et al., 2016). Warming has also driven declines in the southern extent of the range (Wahle et al., 2015; Goode et al., 2019). Harvesters in Maine utilize environmental cues, including water temperature, to determine when and where to deploy fishing gear (Staples, 2017). The Gulf of Maine lobster fishery does not have management-defined seasons, but the fishery tends to increase effort around the time of the spring molt, which is influenced by water temperatures and vary by region within the Gulf of Maine (Staples et al., 2018). This is a fishery that uses the rhythms of nature to optimize catch.

Surfacing the complexities and associated assumptions around the impacts of climate change is critical for successful management. Survey respondents participating in the American lobster fishery viewed their risk to climate change, on average, to be moderately low and adaptive capacity to be moderately high. However, 57% of respondents in this study, which ranged from Maine to Connecticut, stated that climate change is having a negative impact on American lobster. McClenachan et al. (2022) found that 59% of Maine harvesters surveyed were somewhat or very concerned about the impacts of climate change on lobster, compared to 95% of scientists surveyed. The effects of warming temperatures from climate change on American lobster vary in space and time (Le Bris et al., 2018; Staples et al., 2018; Goode et al., 2019) and are greatly simplified in a person's mental model of the situation (McClenachan et al., 2022). However, a fishery does not exist in a vacuum. The American lobster fishery is needing to significantly reduce their risk to North Atlantic right whales, a species that has been greatly impacted by climate change (Record et al., 2019), which will require significant changes to the fishery. Harvester's perceptions of vulnerability from climate change in the American lobster fishery may have shifted since this survey and the McClenachan et al. (2022) survey was conducted due to the fiscal impacts the proposed changes might have.

The striped bass fishery had great success rebuilding in the 1980s but is now seeing population declines again (NOAA, 2018). In the 2022 update assessment it was declared overfished but not experiencing overfishing (ASMFC, Atlantic States Marine Fisheries, 2022). Striped bass is predominantly a recreational fishery, with 15.2 million pounds harvested from 2020-2021 in the recreation sector with 85-90% of what is caught being released alive (ASMFC, Atlantic States Marine Fisheries, 2022). Conversely, the commercial harvest of striped bass was 3.95 million pounds from 2020-2021 (ASMFC, Atlantic States Marine Fisheries, 2022). The 2016 stock assessment update found the striped bass population to have fishing mortality below reference points and spawning stock biomass above their threshold levels (ASMFC, Atlantic States Marine Fisheries, 2016). Hare et al. (2016) would have captured scientific perspectives when the fishery appeared to be in good condition. In the 2018 striped bass stock assessment, the fishery was declared to be overfished and experiencing overfishing (ASMFC, Atlantic States Marine Fisheries, 2019). Our survey captured harvesters' perceptions in 2020, after the fishery had been overfished and experiencing overfishing for a couple years.

Although the striped bass fishery is at low spawning stock biomass and harvesters perceive climate driven impacts, those participating in this commercial fishery have relatively low vulnerability, presumably because few harvesters generate the majority of their income from this fishery (Murphy et al., 2022). Respondents in this study targeting striped bass had, on average, extremely high adaptive capacity likely due to many harvesters using this fishery for supplemental income, as found in Murphy et al. (2022). On average, respondents participating in this fishery had moderately high risk (exposure and sensitivity), driven by perceptions of a negative impact of climate change on the species. Motivations for participating in this fishery have been linked to desires "to get away from the regular routine or simply to be outdoors", not strictly economic incentives (Murphy et al., 2022). All of these aspects of the fishery will impact the risk tolerance of participants. It will be important to understand how tolerant scientists, harvesters, and managers are of different types of risk, interpreting scientific uncertainty, and responding to both. Identifying areas where harvesters are on common ground with the scientific community can help build trust between these groups. Once common ground is established, it may be easier to discuss areas where views differ to address complex management issues under changing conditions.

Contextualizing harvester's immediate concerns

Commercial fish harvesters surveyed in this study portray a complex understanding of climate change and its impacts. Respondents recognize the threat of climate change on fisheries but perceive it to be more of a threat to future generations than an immediate threat to themselves. Most respondents are experiencing stress from changes in fisheries and the environment, indicating climate change may be exacerbating more immediate concerns regarding their fishing businesses. It is therefore not surprising that participants that do believe that climate change is occurring had higher perceived vulnerability on average than those who do not recognize that threat, a phenomenon documented in other contexts as well. For example, grape growers in Australia who were convinced about the reality of climate change had higher perceptions of risk (Fleming et al., 2015), and those who think about climate change more frequently perceive it as a greater risk than those who think about it less often (Ballew et al., 2019).

While it is important to address the immediate risks to fishing communities, such as loss of working waterfronts, focusing solely on immediate risk reduction can come at the expense of the flexibility needed to address long-term risks like climate change (Nelson et al., 2007). Many harvesters in this study currently view climate change as something that will happen in the future and thus as a lower risk. Even within the fisheries management community there exist a variety of perspectives regarding the prioritization of addressing immediate needs versus focusing on long-term resiliency (Nelson et al., 2022). Because of these differences in perceptions, it is important to work with fishing communities, associations, and individuals to develop a shared understanding of how to address the near- and long-term threats to the fishing industry. Collaborative research on the impacts of climate change can serve as a pathway for developing a mutual understanding between harvesters, managers, and researchers about how the ocean is changing.

The results of this survey illuminate the difficulty of addressing the long-term threats from climate change when harvesters are facing what they perceive to be more immediate or pressing stressors, which here specifically include fisheries regulations, market access or stability, and access to working waterfront. These threats are likely perceived as more immediate because they relate to trigger areas, identified by psychologists, that elicit a call to action: personal, abrupt change, something perceived as immoral, happening now (Marshall, 2014). Climate change is perceived as being a slow moving and distant threat which does not tend to set off any of the above triggers people use to identify threats worthy of timely action (Marshall, 2014). We know that individuals who are concerned or alarmed about climate change are the most motivated to respond to the impacts (Grothmann and Patt, 2005; Leiserowitz et al., 2021). This study captures the variability in that level of concern between harvesters and across fisheries, potentially resulting in differing levels of motivation to act among those groups. It also demonstrates that perceptions can vary between harvesters and scientists.

Conclusion

Integrating climate change into all aspects of fisheries management is critical for sustainably managing fisheries into the future. This is necessary to build and support the resilience of harvesters and adopting climate resilient fisheries management practices could contribute to more productive and profitable fisheries globally (Free et al., 2020). However, inclusion of only environmental data will not be sufficient – fisheries need to take into consideration social-ecological factors (Free et al., 2020) and the diverse perspectives of all those involved in a fishery (Holsman et al., 2019). Discussions about climate change and how best to move forward can create conflict, even if all parties believe climate change is occurring. A starting point to reconcile disagreement is understanding the perceptions of harvesters regarding the impacts of climate change and discussing how climate resilience may also contribute to the mitigation of their most immediate threats or concerns. Taking the time and energy to remain curious about how individuals are interpreting the world around them and seeking a place of commonality to foster collaboration will create the best opportunity for success as we seek to build climate-resilient fisheries and fishing communities.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://github.com/lknelson05/climate_perceptions/tree/NE.

Ethics statement

The studies involving human participants were reviewed and approved by University of Washing Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JR: Revised survey for the Northeast and coordinated distribution, coding and quantitative analysis, writing, coordinated writing of co-authors. LN: Developed original survey, Coding and quantitative analysis, writing and editing. SH: Qualitative analysis, writing/editing in all sections. RB: Assistance with quantitative analysis, contextualizing results in discussion, writing and editing. GS: Writing/editing contribution, funding support. AC: Conceptualized and helped develop the survey methods, writing and editing. MC: contextualizing results in the discussion, writing and editing. PL: Conceptualized and helped developed survey methods, writing and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.1049445/full#supplementary-material

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